Through the eyes of a teenager: complexity of real-time Theory of Mind inferences in language comprehension.

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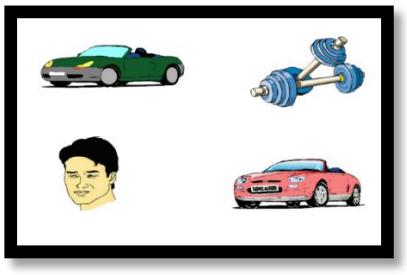
A number of studies have provided evidence for structural and functional changes in the brain areas involved in theory of mind (ToM) (the "social brain") not only during childhood, but also during adolescence, [1]. Recent findings suggest that the online use of ToM shows a prolonged development through late childhood and adolescence, [2]. In order to investigate the role of Theory of Mind (ToM) in language comprehension and its developmental trajectory, we adopted a visual world paradigm from [3] to examine how quickly younger (9-13) and older adolescents (14-18.5) can use knowledge about a character's preferences and desires to make complex ToM inferences and predict that character's subsequent behaviour during discourse, in comparison to adults (25-36). Participants were presented with two sentences in each trial. Sentence (i) introduced a property of a character and (ii) described the character performing an action that is consistent with context given in sentence (i) (**Figure 1**).



Open Context (basic preference and intentions are consistent)
i) *Tom is always telling people that his favourite colour is pink.*
ii) *Last week Tom bought a new car and he deliberately chose a pink car.*

Secret Context (basic preference and intentions are in conflict)
i) *Tom does not want anyone to know that his favourite colour is pink.*
ii) *Last week Tom bought a new car and he deliberately chose a green car.*

Figure 1. Example of visual stimulus that participants viewed while the heard the target sentence (sentence ii).

In the open condition, the character's basic preferences and high-order desires match, whereas in the secret condition the character's basic preferences and high-order intentions are in conflict. The visual display (see **Figure 1**) was presented during the second sentence and was the same for both conditions. Participants also under took standard tests of inhibitory control (IC), working memory (WM) and an Empathy Quotient test. In addition, adolescents and adults also undertook an on-line false belief task, adopted from [4].

Results. Fifty-two participants took part in this study (Adults n=17, M = 27.32 years, SD = 3.57; Adolescents I n=18, M = 16.70, SD = 1.39; Adolescents II, n=17 M = 11.81, SD = 1.43). Statistical analyses were carried out with mixed effect regression models for each time window separately: i) ambiguous noun (e.g. "car") ii) post-ambiguous noun, iii) adverb (e.g. "deliberately"), iv) transitive verb, and v) disambiguating noun. For each time-window a referent preference score was calculated as in [3]: log(Open/Secret) = *ln* ($P_{(Open)}$ / $P_{(Secret)}$). $P_{(Open)}$ refers to the sum of looks to the open referent divided by the total number looks to all ROI's within that trial and $P_{(Secret)}$ is the sum of looks to the secret referent divided by the total number of looks to all ROI's within that trial. Results showed that adults start making anticipatory eye movements towards the target in the *open condition* (pink car) and the *secret condition* (green car) early on from the ambiguous noun ('car') Est.=0.92, SE=.31, t=2.97, $p < .01$), (**Figure 2**). In contrast, both adolescent groups only begin to anticipate the target in both conditions during the transitive verb region ('choose') Est.=0.64, SE=.30, t=2.12, $p < 0.5$. On participants' WM, IC and EQ, younger adolescents

performed significantly worse in all individual measures from older adolescents and adults but older adolescents did not differ from adults. On the on-line False-Belief task, adolescents did not differ from adults.

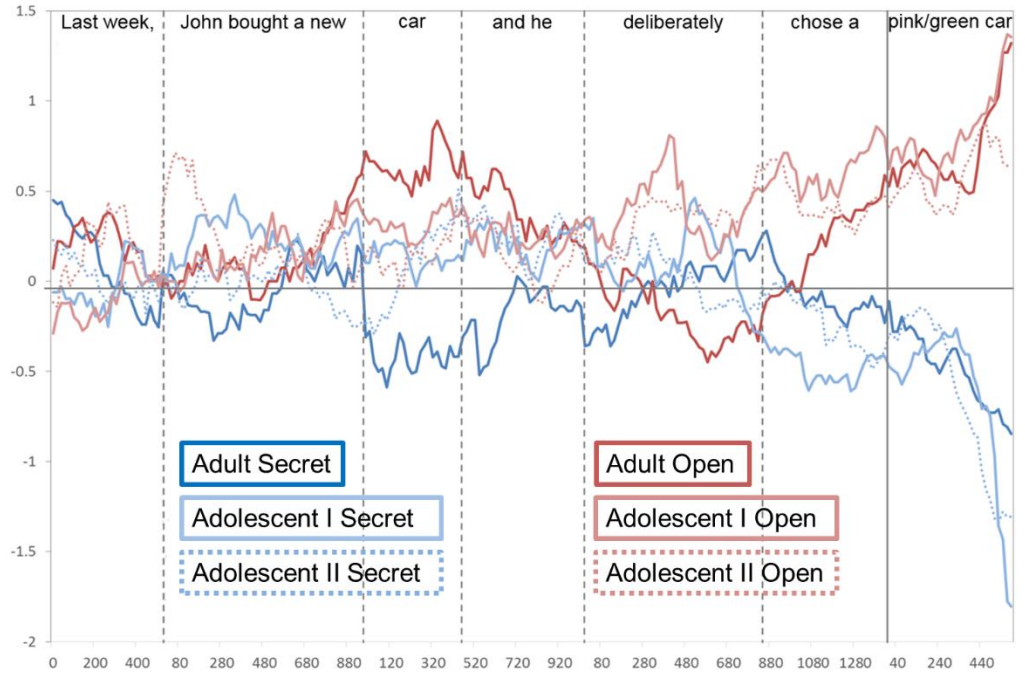


Figure 2. The average log(Reality/Belief) score for each condition and age group. Note that the dashed and vertical lines indicate absolute onsets and average offsets of words in the target sentence.

Discussion. These results suggest age-related differences between adolescents and adults in their online use of ToM. Critically, when reasoning about the character's basic preference and high-order intentions, adults anticipated the target early on in the 'car' region. Adolescents only begin to anticipate the target in both conditions during the 'choose' region, suggesting that adolescents may not be able to use information about others' mental states for language comprehension as quickly as adults. Although WM and IC have been shown to be factors in the application of ToM in previous studies [2,5], our results suggest these are not the only factors in the on-line application of ToM. Our results also point to the conclusion that not all on-line comprehension tasks that involve ToM are equal in terms of ToM inferential complexity, and that such complexity does not necessarily correlate with other task demands, like IC.

References:

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